AU/ACSC/98-050/1998-04

AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

FLIGHT FORMATION DEVELOPMENT FOR ASSAULT SUPPORT AIRCRAFT V-22 AND C-130

by

Kenneth W. Clark, Major, USMC

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

Advisor: Bret Rider, Major, USAF

Maxwell Air Force Base, Alabama

April 1998

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (FROM - TO)
01-04-1998	Thesis	xx-xx-1998 to xx-xx-1998

4. TITLE AND SUBTITLE Flight Formation Development for Assault Support Aircraft V-22 and C-130 Unclassified	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Clark, Kenneth W. ;	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME AND ADDRESS Air Command and Staff College Maxwell AFB, AL36112	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS ,	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APUBLIC RELEASE
,

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This research paper is to be utilized by aircrew involved in the development of aviation tactics and/or operational test and evaluation. Knowledge of aviation operations is required to obtain a comprehensive understanding of the methodology and information presented to support the project conclusions. The thesis of this research paper is to develop an optimized, mutually supportive formation(s) for the V-22 and C-130. I will use the capabilities and limitations of the human eye to determine an aircraft?s POD and correlate it to the aircraft?s field of view (FOV). The methodology of research will begin by defining a set of formation principles. My historical research determined those principles to be mutually supportive look-out, maneuverability, flexibility, command and control, protection, self-navigation and unity of effort. To better support the projects POD studies, an understanding of how the human eye interacts with the effects of luminance, target size and contrast is necessary. The project?s two case studies (Look-up and Look-down), utilized interpolated data from a report completed by the RAND Corporation. This research project departs from the RAND report by analyzing the POD distances to develop optimized aircraft formations. The research scope provides the necessary assumptions and limitations and includes the following: flight visibilities, search areas, field of view (FOV) restrictions and background to aircraft contrasts. The case study findings determined that the optimum distances to detect incoming aircraft is 2 ? 2.65nm for a 50% POD and 1.6 ? 2nm for a 75% POD. The optimum formation is the three-aircraft division, using the inverted ?Y? formation. For future research and development, additional efforts should be directed towards determining the adverse effects of movement in a formation. Aircraft dispersion distances should also be verified through flight tests to establish the practical limits of formation lateral separation and mutual support. Additionally, any formation that is optimized according to the formation principles will also possess significant benefits against ground threats.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19. NAME OF RESPONSIBLE PERSON
			Public Release	73	Fenster, Lynn lfenster@dtic.mil
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703767-9007 DSN 427-9007

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39.18

Disclaimer

The views expressed in this academic research paper are those of the author(s) and do not reflect the official policy or position of the US government or the Department of Defense. In accordance with Air Force Instruction 51-303, it is not copyrighted, but is the property of the United States government.

Contents

Page

Illustrations

Page

Tables

Page

Preface

The idea for this research project began while I was stationed at Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) in Yuma, Arizona. As a KC-130 instructor, I had the privilege of attending one of the V-22 Operational Tactics Guide (OTG) Working Sessions. I attended several of the meetings involved in the preliminary development of flight formations. These meetings made me acutely aware of the lack of understanding between the helicopter and fixed wing communities on what constituted the appropriate way to conduct formation flight. The challenge for me is to find some common ground between the communities to develop formation guidelines, centering on the specific aircraft's field of view and mutual support. Keeping this in mind, my research will provide some insight into the future development of aircraft formations for both the C-130 and V-22.

I would like to gratefully acknowledge the professional and courteous support provided by the Air University Library Staff and the Air Force Historical Research Agency. Their assistance made my research paper a more manageable and enjoyable project. A special acknowledgement to my faculty research advisor, Major Bret Rider, and his boss, LtCol. Tim Sakulich for assisting this mathematically challenged Marine in deciphering the cited RAND Report probability of detection (POD) calculations. Numerous unnamed individuals also deserve my thanks for providing the necessary V-22 and C-130 data.

Abstract

This research paper is to be utilized by aircrew involved in the development of aviation tactics and/or operational test and evaluation. Knowledge of aviation operations is required to obtain a comprehensive understanding of the methodology and information presented to support the project conclusions. The thesis of this research paper is to develop an optimized, mutually supportive formation(s) for the V-22 and

C-130. I will use the capabilities and limitations of the human eye to determine an aircraft's POD and correlate it to the aircraft's field of view (FOV). The methodology of research will begin by defining a set of formation principles. My historical research determined those principles to be mutually supportive look-out, maneuverability, flexibility, command and control, protection, self-navigation and unity of effort. To better support the projects POD studies, an understanding of how the human eye interacts with the effects of luminance, target size and contrast is necessary. The project's two case studies (Look-up and Look-down), utilized interpolated data from a report completed by the RAND Corporation. This research project departs from the RAND report by analyzing the POD distances to develop optimized aircraft formations. The research scope provides the necessary assumptions and limitations and includes the following: flight visibilities, search areas, field of view (FOV) restrictions and background to aircraft contrasts. The case study findings determined that the optimum distances to detect incoming aircraft is 2 – 2.65nm for a 50% POD and 1.6 – 2nm for a

75% POD. The optimum formation is the three-aircraft division, using the inverted "Y" formation. For future research and development, additional efforts should be directed towards determining the adverse effects of movement in a formation. Aircraft dispersion distances should also be verified through flight tests to establish the practical limits of formation lateral separation and mutual support. Additionally, any formation that is optimized according to the formation principles will also possess significant benefits against ground threats.

Chapter 1

Research Background

Introduction

You can't hit what you can't see.

—Unknown

From the inception of military aviation, the ability to see a potential target has always been vital. The old adage is very poignant for the fighter community, because their mission is to find and destroy targets! But what about pilots who rely on remaining undetected as their only means of defense? These pilots and their aircraft commonly fall into what is known as the assault support community. This community includes rotary wing aircraft such as the CH-46, CH-47, CH-53, and fixed wing aircraft such as the C-130, C-123. Both groups have distinct and varied capabilities. The newest aircraft addition to this community, the V-22, Osprey, bridges the gap between rotary and fixed wing capability by possessing the speed and range of a C-130 while landing and taking off like a helicopter.

With the advent of the V-22, a re-evaluation of existing helicopter and fixed wing formation procedures must be conducted. This re-evaluation is necessary to ascertain if the passive self-defense aspect of assault support formations can be improved, by optimizing the detection of enemy aircraft through formation mutual support.

Thesis Statement

The purpose of this research paper is to develop an optimum, mutually supportive formation for the V-22 and C-130. I will do this by utilizing the capabilities and limitations of the human eye to determine an aircraft's probability of detection (POD) and then correlate it to the aircraft's field of view (FOV).

Overview

From both a historical and current perspective, this research paper describes why formations are flown. The WWII perspective ranges from bomber formations flown for target accuracy and interlocking fields of fire for self-defense, to fighter formations for mutual support during air-to-air engagements. With the Korean War came the advent of the jet aircraft with expanded flight envelopes and reduced reaction times. The current perspective is drawn from the assault support community, both rotary wing and fixed-wing, formation procedures and tactics. A comparative examination of perspectives is required to provide a comprehensive set of formation principles. These principles provide the guidelines to develop optimized formations for the V-22 and C-130.

Following the historical discussion, the complexities of the human eye and its capabilities and limitations as a sensor is examined to highlight the critical elements of sight which are needed by aircrew to maximize visual detection of aircraft. These elements will assist aircrew in understanding and appreciating the complexity of optimizing formations based on mutual support. Interwoven with the examination of the eye is the necessity for aircrew to optimize their capabilities for detecting aircraft. This is done by understanding and applying the fundamental elements of an efficient search. To accomplish this, aircrew must be trained in establishing a disciplined lookout doctrine.

The next portion of the project will be to establish limitations and assumptions. These items are essential to provide a framework for understanding the research paper findings while maintaining the focus on the research thesis.

In the optimized flight formation development portion of the paper, the ability to detect aircraft is analyzed through the use of formulas generated for the USAF by the RAND Corporation. These formulas act as an approximation of dynamic environmental conditions and provide a baseline for referencing the probability of detecting an aircraft. This research project departs from the RAND report findings by analyzing the POD distances to develop optimal aircraft formation. The conclusion combines the knowledge and understanding of the POD with the V-22 and C-130 field of view (FOV) limitations to develop formations based on mutual support. The summary represents my recommendations to further the development of formations in the assault support community.

Chapter 2

Historical Background of Formation Development

> *All tactical formations are a compromise between maximum maneuverability and maximum mutual support, and the extent of the compromise depends upon the requirements of the mission to be flown.* [8]
>
> —Major F.C., Blesse, USAF

Unit histories were compiled and written during WWII to chronicle the development of aviation doctrine and tactics. Many bomber unit histories reflected the development of formations by discussing how and why they flew formations. The 1st Bomb Division, Eighth Air Force stated the factors that influenced their formations included security of force (protection), size of the bomb pattern, crew member visibility (look-out), flexibility, flak assessment and command and control.[1] The lst Bomb Division history goes further by stating,

> The considerations in formation flying of visibility, flexibility, ease of flying, and ability to be commanded in the air, are all tied together. Every new formation had to be analyzed carefully to study each of these points. You needed to make sure that when the planes moved into the desired formation, the result was not an unwieldy group of planes echeloned into position where they could not be sure of what was going on around them, with the possibility of a crash because you slide into a blind spot in the formation.[2]

The end result of the WWII bomber unit histories was that a set of guidelines emerged to ensure basic fundamentals of formation flight.

Fighter formation development, on the other hand, had a different mission. Their formation development emphasized offensive capability. Formation maneuvering and tactics were essential to achieving advantages. For that reason, the fighters considered surprise to be the most important factor in air combat.[3] To achieve tactical surprise, fighters often maneuvered to take advantage of environmental conditions that minimized their POD and exploited any blind areas in the enemy formation. For example, during evening or early morning hours, fighters attacked from the darker part of the sky. This was primarily due to the fact that target aircraft would be silhouetted and more visible with a bright background than with a dark one.[4] This example minimized the aircraft's POD by reducing its contrast. By reducing contrast levels, the attacker has the advantage of surprise. Simply put, the reduction in illumination/contrast decreased the observer's ability to see the fighter (visual acuity).

The use of such tactics contributed to the heightened awareness of mutual support and vigilance in the development of formations and counter tactics. It was noted in the Air Intelligence Summary No. 16, December 31, 1941 - January 23, 1942, *RAF Fighting Tactics*, that when German aircraft appeared in one direction, vigilance in the other directions must not be relaxed, because other aircraft may be providing support to the aircraft sighted.[5] To WWII fighter aircrew, mutual support and vigilance were considered essential to survival. The culmination of WWII fighter formation procedures and tactics were summed up in a memorandum from the Headquarters VIII Air Force to the Headquarters VIII Fighter Command. "The fundamentals in any formation flown are that the airplanes must be positioned so they can support each other. Airplanes must be spaced loose enough to give each pilot freedom of action, rapid maneuverability and opportunity to conduct continuous 'eye search' of the sky."[6]

The Korean War provided the next opportunity to build upon WWII experiences in formation development

> As in WWII, the ability to see the enemy first provided a great advantage in Korea. Thus, aircrew needed to maximize their ability to detect aircraft through hard work and constant practice. The ability to detect aircraft first has become an increasingly critical task as the speed and altitude of aerial warfare has increased. Many potentially good fighter pilots have been unsuccessful, simply due to the fact they cannot search the sky effectively.[7]

This observation and the continued experiences of many Korean pilots led to a manual written by Maj. F.C. Blesse for the Fighter Weapons School at Nellis Air Force Base, *No Guts, No Glory*. The manual is a combination of tactics and procedures built upon by Maj. Blesse during two tours in Korea. In his manual, he identifies the objectives of tactical formations:

- Achieve maximum maneuverability.
- Achieve maximum mutual support and visual cross-cover.
- Assign definite responsibilities to each member of the flight and provide a chain of consecutive authority in order to maintain unity within the flight, throughout the mission, regardless of any unforeseen difficulties.
- Enable each member of the flight to perform cruise control consistent with the requirement of the mission and to accomplish his own navigation, in addition to fulfilling the duties required from all members of an effective combat team.

Maj. Blesse also states that all tactical formations are a compromise between maximum maneuverability and maximum mutual support. The extent of compromise depends upon the requirements of the mission to be flown.[8] Many elements of WWII formation development can be seen in the tactical formations used in Korea. Korean War formations and procedures did not deviate substantially from the guidelines established in

WWII, though jet aircraft expanded the flight envelope and reduced reaction times associated with detection of incoming aircraft.

The current perspective of formation procedures and tactics, fixed wing (C-130) and rotary wing, will be examined to complete the historical comparison of formation development. An examination of USAF and USMC C-130 regulations and tactical manuals revealed a close alignment in formation procedures and tactics. Due to my familiarity with USMC procedures, I chose the KC-130 tactical manual as the primary source of

C-130 formations and tactics. The manual states,

> The objective of flying formation is to provide a method to employ and control a flight of aircraft to accomplish an assigned mission in a manner that will minimize the effectiveness of any threat opposition while maximizing the chance for success. Formations should provide the following:
>
> - Mutually supportive lookout doctrine
> - Ease of control and coordination
> - Maneuverability and flexibility
> - Ability to deliver a large amount of fuel or cargo
> - Ability to divide mission workload.
>
> It is also important to note that most assault support formations are to be conducted in a low-altitude environment to delay and/or deny enemy detection, as well as complicate the enemies' ability to acquire, track and engage a target.[9]

Rotary wing formation procedures were obtained from USAF, MH-53 Special Operations, USMC CH-53, CH-46 and UH-1 tactical manuals and US Army helicopter tactical flight procedural manuals. Helicopter formation guidelines stated that formations should provide:

- Maneuverability
- Flexibility
- Mutual support (lookout)

- Protection
- Command and Control (C^2)
- Unity of effort.

Flight formations must also provide a balance between mutually supportive lookout, maneuverability, flexibility, flight control and unity of effort.[10]

Comparison of the historical and current methods of conducting formation flights and their associated tactics shows us that formation procedures and tactics have been evolutionary in their development. As a result, the following comprehensive list of principles represent what a formation should provide as a means of achieving our mission objectives:

- Mutually supportive lookout
- Maneuverability
- Flexibility
- C^2
- Protection
- Self-navigation
- Unity of effort.
-

Thus the goal of developing an ideal formation would be to optimize the above principles..

Notes

[1] History, *History of Formation Flying in the 1st Bomb Division*, Eighth Air Force, England, 1942-1945, Pg. 10
[2] Ibid, 12
[3] Air Intelligence Summary No.16-Squadrons, December 31, 1941, R.A.F. Fighting Tactics, 23 January 1942, Pg. 3
[4] Ibid, 4
[5] Ibid, 4
[6] Stanely, Julian C., Actng. Chief of staff, HQ VIII Air Force, Memorandum, To HQ VIII Fighter Command, Subject Operations, Fighter Tactical doctrines, 20 March 1943, Pg. 1
[7] W., L., Van Gilder, *Realistic Training: The Key to success in Aerial Combat*, Fort Leavenworth, KS, 1979, Pg. 64

Notes

[8]Blesse, Maj. F., C., “No Guts, No Glory”, *Fighter Weapons Newsletter Special Issue: Fighter Tactics*, no. 1 (March 1955), Pg. 3

[9] USMC, KC-130 TACTICAL MANUAL, NWP 3-22.5-KC130, Vol. I, NAVAIR 01-75GAA-1T,May 1997, *Chapter 5, Low Level Formation, Pg. 5-1 and Chapter 12 Low Altitude Tactics, Pg. 12-1*

[10] USMC, CH-53 TACTICAL MANUAL, NWP 3-22.5-CH53, Vol. I, NAVAIR A1-H53BE-TAC-000, August 1997, *Chapter 2, Formation Flying*. Pg. 2-1

Chapter 3

The Human Eye as a Sensor

The human eye is a versatile sensor with many capabilities and limitations. The application of those capabilities and the knowledge of the its limitations will provide a means of developing formations based on mutual support. The use of mutual support requires an explanation of the key factors and conditions that affect the eye's ability to detect aircraft while providing mutual support.

Visual Acuity

Visual acuity is the primary capability that allows the eye to detect aircraft. The *Handbook of Perception and Human Performance, Vol. I (1986)* defines visual acuity as the measure of the resolution capability of a visual system in terms of the smallest, high-contrast detail to be perceived at a given distance. Visual acuity is normally expressed as a ratio of 20/20 vision (Snellen acuity). "For example, 20/30 indicates that a person can barely read at 20 ft what a normal (20/20 vision) person can read at 30 ft. 20/10 vision indicates a person can read at 20 ft what a normal person must bring to 10 ft."[1] The minimum visual acuity acceptable for aircrew is 20/20. During the detection and identification of aircraft, 20/20 vision is one of the most important factors in achieving high levels of performance.

Factors Affecting Visual Acuity

Luminance

Luminance is defined as the amount of light measured in lumens per unit area that intercepts a surface at any given point (amount of light striking a surface). Luminance levels must remain high, because a significant amount of light is needed to take full advantage of the eye's visual acuity and contrast sensitivity. However, during the course of a flight the amount of light may change, which will significantly affect the aircrew's ability to detect aircraft. As a rule, as light conditions begin to decrease, the contrast sensitivities affecting the eyes visual acuity will also decrease. Therefore, optimum luminance levels will maximize visual acuity and improve the speed at which aircraft can be detected.[2]

Contrast

Contrast, by definition, is the measure of illuminance difference between a target and its background. The effects of contrast within a visual scene, coupled with visual acuity play a significant role in detection of aircraft. When the contrast of a target is low, the target will have to be larger for it to be detected at the same distance as a much smaller target with high contrast.[3] The *Human Engineering Guide to Equipment Design (1972)* states, the interaction of variables with a target against a mottled or patterned background, creates difficulty in detection, especially when other objects in the field resemble the aircraft's size, color and shape, or luminance. For military aircraft, a low contrast condition is obviously more desirable than a high contrast one. It was noted in the RAND report that when rapid discrimination of very small targets is necessary, high intensities of light and large contrasts are required.[4] To reduce contrast differences, many different military aircraft paint schemes have been tested. No one paint scheme has worked for all environments, but a low contrast scheme is necessary to reduce an aircraft's POD.

Target Size

The effect of target size alone plays an important part in the ability of the eye to detect aircraft. Under optimal conditions, as the perceived size of the aircraft becomes large enough for the eye to detect, a detection distance is obtained. But, the factors of illumination/luminance and contrast interact to create changes in the actual detection distances. The relationship between illumination/luminance and contrast is directly proportional to the POD of an aircraft (target). The required size of the aircraft (target) to equal the same detection distance as above; however, is inversely proportional to the levels of illumination/luminance and contrast.

Prediction of Sighting Distances

The prediction of sighting distances is a complex and difficult problem. Researchers have developed models to predict the distance at which specified targets should be visible to aircrew. These models serve as very useful tools in estimating an aircraft's probability of being detected, but cannot account for all the variables or the changing conditions encountered in flight. For this research project, in addition to those variables previously mentioned, the POD is influenced by aspect angle (angular motion), limited search time, terrain features, visibility (haze), weather and offset distance. These variables will be presented in greater detail in Chapter 5 to assist in establishing the optimum distances for detection of aircraft.

Notes

[1] Sanders, M.S., McCormick, E.J., *Human Factors in Engineering and Design*, McGraw Hill, NY, 7th Edition 1993, Pg. 95

[2] Woodson, Wesley E., *Human Engineering Guide for Equipment Designers*, U.S. Navy Electronics Laboratory, San Diego, 1954, Pg. 2-14

[3] Wiener, Nagel David C., *Human Factors in Aviation*, Academic Press Inc., 1988, Pg. 98

[4] Dugas, Doris, J., *Visual Detection of Low Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model*, Report prepared for USAF Project RAND, R-885-PR December 1971, Santa Monica CA, Pg. 15

Chapter 4

Aircraft Detection and Avoidance

> *The ability to see an aircraft while remaining unseen provides the only advantage and perhaps the only difference between life or death, mission success or failure.*
>
> Major K.W. Clark, USMC

As previously stated, the human eye, as an instrument of detection, relies on its visual acuity to detect aircraft. If visual acuity is the key to detecting aircraft, then a lookout doctrine, which encompasses the knowledge and application of aircrew training, accurate distance and range estimation and a visual scan, is the only means to ensure employing an effective defense.

Searching

Visual Scan

An essential aspect of lookout doctrine is the systematic application of a visual scan. As a means of instruction, aircrews need to be taught that a scan must be systematic, coordinated and vigilant to ensure proper lookout coverage. By establishing overlapping search areas, around the formation, continuous coverage is obtained with an increase in the probability of detecting an aircraft. This increased POD is extremely important to the assault support community, because detecting threat aircraft first provides a needed advantage. Aircrew developing a scan and building a good lookout doctrine is the basis of mutual support.

Acuity and Peripheral Vision

Aircrew given the task of conducting a search for enemy aircraft will be required to continuously scan their respective sectors of responsibility. An effective scan will require extensive eye movement within their sectors to maximize the probability of detecting an aircraft. Movement of the eyes is necessary because certain areas within the eye are more sensitive; consequently, detection of aircraft is more efficient if the searcher moves his eyes more frequently.[1]

The eye movement is required to maximize the POD, because visual acuity deals primarily with the eye's central vision. As the distance increases away from the eye's central vision, visual acuity diminishes rapidly. For an aircraft to be seen, the eyes must be focused within an angle as small as one degree. At progressively greater peripheral angles, aircraft size must be larger to be detected. This equates to a smaller distance from the observer to the target aircraft or a larger target aircraft. Therefore, to be perceived by peripheral vision, the aircraft must be several times larger and/or closer than when seen through the eye's central vision.[2]

While conducting searches, the eye has a tendency to fixate on different points of interest within its FOV. These points of interest will cause aircrew to continue to make numerous, small fixation sights around the specific area of interest. Although eye fixations are a natural tendency, excessive fixation causes the remainder of the total search area to be neglected.[3]

Estimating Size and Distance

The ability of aircrew to estimate distances to aircraft without proper training represents a very difficult, if not impossible, task. The eye has an extraordinary capacity for detecting aircraft under a wide range of variables, but is very poor at estimating absolute values (distance). To obtain an accurate estimate, a direct relationship must exist between the observers' perception of an aircraft's actual size and the estimation of the distance to the aircraft. For example, if an aircrew is attempting to estimate the distance to a target aircraft whose size is unknown to him, his ability to judge that distance is distorted. If the aircrew is familiar with the target aircraft's size, or a separate object at a known distance appears within the FOV, distance estimations will be more accurate. However, aircrew will normally underestimate distances, particularly when other objects that provide distance cues in the FOV are lacking. If no other objects are in the aircrew's field of view – as when an aircraft is high in the sky – estimates of distance are usually too short. As a result, it is almost impossible to estimate the distance of an aircraft seen against a clear, cloudless sky, unless it is fairly close or its size is known.[4]

Vigilance

N.H., Mackworth (1957) defines vigilance (sustained attention), as "a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment."[5] The success of aircrew to search for, and detect an aircraft demands sustained attention. Due to the level of aircrew mission tasking, the ability to maintain sustained attention typically decreases over time. This is a phenomenon known as vigilance decrement. Vigilance decrement normally manifests itself in a steady reduction in the aircrew's ability to maintain a high probability of detection and/or an increased reaction time.[6] As a result, high vigilance tasking should only be directed by the aircraft commander or pilot in command during high threat portions of the mission. Conversely, during periods of known low or no threat, aircrew should be directed to relax their vigilance to realize a greater level of efficiency during periods of high threat.

Lookout Doctrine and Discipline

Mission Tasking

The use of an efficient lookout doctrine, coupled with a disciplined application, can enhance an aircrew's probability of detecting an aircraft. The ability of aircrew to conduct such a lookout is dependent upon a number of factors. One such factor is mission tasking. Mission tasking can have a detrimental effect on the ability of aircrew to remain vigilant, as well as their overall effectiveness to conduct lookout responsibilities. For example, when a pilot is flying formation, he is not only responsible for terrain avoidance, scanning internal instrumentation, communication, and navigation, but also maintaining his position within the flight. Although the use of an instrument such as a heads-up display and a division of workload between crewmembers can minimize tasking, the other responsibilities represent time spent away from scanning his assigned sector. Poor management of mission tasking can adversely effect the POD. The proper approach to mission tasking is to provide aircrew with sufficient training and exposure to mission tasking while conducting lookout responsibilities to minimize the detrimental effects of a high task load on aircrew.[7]

Aircrew Training

Aircrew training supports the lookout doctrine and discipline of an aircrew, which is critical to the success, or failure of a mission. Therefore, aircrew must be provided the knowledge and then taught the detailed application of the skills associated with that knowledge to be of any assistance in achieving a high POD of aircraft.

Threat Recognition and Tactics

Aircrew must be able to identify threat aircraft, because knowledge of threat aircraft (i.e., size and configuration) aids in detection and distance estimation. Additional knowledge of an adversaries' disadvantages such as excessive exhaust smoke and paint scheme can provide detection and identification cues. The aircrew must also be versed in threat tactics. Because a thorough knowledge of threat tactics will enable aircrew to anticipate probable courses of action, if an airborne attack occurs.

Distance and Range Estimation

Aircrew have the difficult and important task of range estimation. Range estimation can be accomplished when coupled with known aircraft size, but a common disparity among aircrew is quantifying size to the correct distance. The data in Table 1 provides a comparative list of distances and the associated weapons engagement ranges to assist aircrew in estimating distances.

Notes

[1] American Institutes of Research, *Human Engineering Guide to Equipment Design (Revised Edition)*, Washington, D.C., 1972, Pg. 54

[2] Ibid, 54-55

[3] Ibid, 55

[4] Ibid, 61

Notes

[5] Boff, Kaufman and Thomas, James P., Eds. *HANDBOOK OF PERCEPTION AND HUMAN PERFORMANCE:, Vol. II, Cognitive Processes and Performance*, John Wiley and Sons, 1986, Vigilance Pg. 43-3

[6] Ibid, 43-6

[7] Ibid, 43-16

Chapter 5

Research Project Scope

Limitations and Assumptions

The research scope sets the practical limits of this project. Setting the limits allows for a subjective evaluation of how and why certain variables were established to assist in any follow-on research. The visibilities are fixed at very clear (15nm), clear (10nm) or light haze (5nm) to establish a comparative norm and are representative of moderate to light environmental conditions. The patrolled search area is limited to $25nm^2$. This is an established limitation from the RAND report. If the search area is increased, the probability of detecting an aircraft or a formation of aircraft, attempting to infiltrate the area would be decreased. The visual FOV from the infiltrating aircraft have a practical cockpit limitation of 90^o. (See Figure 10 and 12)

Due to research limitations, the formations being developed will address only the enroute phase of a mission. The research project investigates the probability of an aircraft being detected as it attempts to infiltrate patrolled airspace. The infiltration is conducted at low-altitude over an area of forested rolling hills to negate or minimize radar detection. Additionally, the air threat has a limited radar look-down capability. Therefore, visual observation will be the primary means of detection.

Methodology

To accomplish the goal of developing an optimum, mutually supportive formation, flight formation estimates of dispersion and geometry must be predicated on the capabilities of the human eye. To quantify the eye's ability to detect aircraft, a threshold of 50% and 75% POD is used as a reference. These references are used as the basis for establishing the optimum distance for mutual supportive lookout. Due to the complex nature of the environment, it was necessary to set many variables as constants to provide snapshots to simplify computations. Central to the analysis of this project was a report prepared by the RAND Corporation for the United States Air Force called *Visual Detection of Low-Altitude Penetrators and Co-Altitude Interceptors in Air Defense: An Application of the Search Model*, by Doris I. Dugas.[1] The methodology of defining a select number of variables and comparing them to demonstrate the effects on the POD was retained from the RAND report. The Look-down and Look-up case studies in this research project differ from the RAND report, because the V-22 and C-130 POD data was interpolated and then analyzed from a perspective of developing POD distances to support optimized formations.

Case Studies

In the look-up case, an aircraft is infiltrating at low altitude while searching for a patrolling aircraft in a prescribed search area. (See Figure 1) In the look-down case, there is a patrolling aircraft at medium-altitude with two crewmembers searching a prescribed area for low-altitude aircraft. (See Figure 2)[2]

Findings

Effects of Altitude, Target Size and Visibility

The findings of the look-down case study demonstrate the effects of variations in altitude, target size, and visibility has on the POD. The effects of altitude and target size on an aircraft's POD are presented in Figure 3. The ability of a patrolling search aircraft at 10,000 feet to detect a single infiltrating C-130 is below 75% and 50% POD from a distance of 1.1 - 1.2nm and 1.6 - 1.7nm respectively. This decreases to less than 20% POD at distances greater than 2.5nm. Comparatively, at 5,000 feet, a 75% and 50% POD is obtained from a distance of 0.9 - 1.0nm and 1.3 to 1.4nm respectively. Again this falls below 20% POD at distances greater than 2.5nm. In Figure 4, three visibilities were compared utilizing a constant altitude to determine the POD. A single infiltrating C-130 obtained a 50% POD at 1.9nm or less with a visibility of 15nm, 1.5nm or less at 10nm visibility, and 0.6nm or less at 5nm visibility. As a comparison, at no time could a single infiltrating V-22 be detected with a greater than 50% POD out to 1.4nm for all visibilities. Within the confines of this project, the optimum distance and visibility conditions required for the detection of a single infiltrating V-22 or C-130 is 1.4nm and 1.9nm, respectively, and 15nm visibility. The case study validates the simple fact that detection probabilities are lower as the target size decreases, visibilities decrease or search altitudes increase.[3] It also demonstrates that lateral separation in excess of 1nm can achieve substantial reductions in the detection of aircraft in a formation

Effects of Contrast

The contrast values in Figure 5 are reflective of data obtained from a visual scene with various paint schemes compared against a forested background. The gray and olive-drab paint schemes have lower contrasts, which results in a reduced POD. The data for a single, infiltrating V-22, with a gray or olive-drab paint scheme, against a searching, patrol aircraft at 5,000 feet required the patrol aircraft to close within 0.75 - 0.5nm before obtaining a greater than 50% POD. For a single infiltrating C-130, the same POD is obtained at a distance of 1.25 - 0.75nm. The POD range can be significantly increased or decreased depending on how an aircraft's paint scheme blends with its background (high vs. low contrast).

Effects of Offset Distances

Offset distance is defined as the lateral distance between two aircraft with reciprocal headings. The specific effects of offset distances are difficult to compute. However, it is important to understand that as offset distances become greater than 1nm, the POD begins to degrade. This degradation is a result of the shorter time spent within the postulated search area as well as the increased slant ranges. The RAND report shows that offsets of greater than 3nm reflected the fact that a greater than 50% POD was never obtained for either the V-22 or the C-130.

Effects of Aspect Angle (Relative Heading)

From the infiltrator's (low to high) perspective, one of the greatest impacts upon detection is the patrol aircraft's aspect angle. In the RAND report, the beam aspect of the patrol aircraft was utilized, because it closely approximated the average of all aspects from the frontal to the plan view.[4] As a result, an increase in offset and aspect angle creates a larger projected target area. When added to angular motion, this greatly increases the chances for detection.[5] Figure 6 demonstrates that the infiltrator's aircrew obtains a POD of greater than 50% (at 2.5nm distance) and 75% (at 2nm distance) against a patrolling aircraft with a visibility of 10nm and a 90^{o} (beam) heading. For a 180^{o} (frontal) heading, the distance is 1.4nm and 1.2nm, respectively. Table 2 provides a comparison of actual field test data and demonstrates the accuracy of the search models in differing conditions of visibility, contrast and altitude.

Effects of Visibility (Weather)

Visibilities have a large impact on the POD of aircraft. In Figures 7 and 8 a comparative depiction of the detectability of the infiltrator and the patrol aircraft are provided. In clear conditions, the V-22/C-130 probability of being detected with a greater than 50% POD ranges from 1.1 - 1.3nm. Comparatively, the probability of the patrolling aircraft being detected varies with the aspect angle ($90 – 180^{o}$), but the range increases to 1.5 - 2.6nm to obtain a greater than 50% POD. For hazy conditions, the patrol aircraft has to be within 0.5nm to obtain a greater than 50% POD for a single infiltrating C-130 and less than 0.5nm for a V-22. In contrast, the probability of the patrol aircraft being detected is greater than 50% POD at 1.5 - 2.5nm, depending on aspect angle. In light of the data presented, it is important to remember that the case studies have shown that the POD in search problems is sensitive to a number of variables.[6] Even with the possible variances, the methodology selected to determine the POD provides an estimation that is beneficial. It provides a range at which aircrew can expect to see an aircraft. As a result, the effects of visibility reinforce the case study findings; the patrolling aircraft will be seen by the infiltrating aircrew first, provided conditions for detection are optimized.

Single vs. Multiple Aircraft Probability of Detection

Up to this point, the entire case study is predicated on a single aircraft's POD. This is primarily due to the scope of the original RAND report, but was also necessary to establish a baseline for comparison with formation POD. The comparison of single versus multiple aircraft POD is the subject of a Tactical Air Warfare Center study entitled, *Low-Altitude Aircraft Detection Probability*. In that study, the penetrating aircraft flew in formations of one, two or four, while interceptors searched for them. During the tests, only 25 % of the test penetrations with single aircraft were detected, but 48% of the aircraft flying in pairs were detected, and 60% of the groups of four were detected. Within the test area, the larger formations, (2+ aircraft), were restricted by the size of the search area, and their target size and movement significantly increased the POD. The test did not specify the separation between aircraft, but from evaluation of the pilots' comments; they appeared to have problems flying formation while maintaining a good lookout.[7] This represents a mission tasking conflict between flying formation and performing mutual supportive lookout (as noted in Chapter 4, Mission Tasking) and should be avoided. The overall assessment of this test is simple, if the proximity of the aircraft within the formation remains close; the human eye will process the entire formation as a single target. As a consequence, it is essential to maximize formation dispersion (distance between aircraft), to reduce the eye's threshold of detection based on target size. This also reduces the probability of the other aircraft in the formation being detected because of the dispersion. In addition, if movement within the formation is excessive, it has the unwanted effect of drawing the attention of the patroller's or searcher's eye.

Target (formation) size and movement must be minimized through formation dispersion to avoid detection. Dispersion also has the added benefit of reducing aircrew workload to allow for a balance between mission tasking, formation flying and mutual supportive lookout.

Notes

[1] Dugas, Doris, J., *Visual Detection of Low Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model*, Report prepared for USAF Project RAND, R-885-PR December 1971, Santa Monica CA

[2] Ibid, 1

[3] Ibid, 15

[4] Ibid, 26

[5] Ibid, 26

[6] Ibid, 32

[7] Defense Technical Information Center (DTIC), *Low-Altitude Aircraft Detection Probability*, Tactical Air Command, USAF Tactical Air Warfare Center, Eglin Air Force Base, Report no. TAC-TR-65-65, September 1965, Pg. 5

Chapter 6

Conclusion: Optimized Flight Formations

How do we optimize flight formations for mutual support? Although the concept is quite simple, it is seldom given serious analytical consideration by aircrew. During the research for this project, no references I found gave specific guidance on why, how or at what lateral spacing a particular formation needed to optimize mutual support. Nor did I find any guidance as to the why or how or any of the other principles of formation flight. Sources I did find on the other principles of formation flight were vague. Sources merely stated particular formation(s) had to be utilized in certain instances. One source stated that dispersion is based on mission, enemy, terrain, troops and fire support available, time, space and logistics (METT-TS-L). While the METT-TS-L statement is somewhat true, and a generic distance can be helpful, neither is sufficient to address the specifics associated with tactical threats. As a consequence, it is the intent of this chapter to provide an optimized formation to specifically address an airborne threat, while providing an explanation of why certain aspects of the formation are utilized. I hope that by presenting this research paper, it will lead to further operational testing so that specific formation guidelines can be developed to optimize formations throughout the assault support community.

Application of Case Study Findings

To develop optimized formation(s), we must extrapolate and apply the research case study findings for the POD. The 50% and 75% POD reference distances are then used in conjunction with the cumulative fields of view to form detection zones. Using the formation principles and detection zones, balanced, mutually supportive and optimized formation(s) are determined. Base formation size (number of aircraft) is also examined to provide a recommended number of aircraft within a formation. Once the optimum formation(s) is determined, an examination of its advantages and disadvantages is necessary.

Probability of Detecting a Searching Patrol Aircraft

It has been estimated through interpolation of the RAND report data that the V-22/C-130 aircrew have a greater than 50% and 75% POD for a searching aircraft (180 to 90^{o} aspect angle) in clear weather at distances of 1.45 to 2.65nm and 1.2 to 2.0nm, respectively. However, the aircrew of the searching patrol aircraft that is attempting to locate a single infiltrating V-22 had a greater than 50% POD at a distance of 1.05nm and a greater than 75% POD at 0.65nm. Comparatively, the single C-130 was detected with a greater than 50% and 75% POD at distances of 1.35nm and 0.85nm, respectively. It is important to remember that the range data for detection of the searching patrol aircraft is reflective of both the 180^{o} (head-on) and 90^{o} (beam) aspect. The POD distances increase significantly if the search aircraft or the V-22/C-130 is maneuvering, because the effects of motion will enhance detection.

V-22 and C-130 Cumulative Field of View

The V-22 cumulative field of view is determined by either obtaining or calculating the vision plots from each viewing station. The V-22 cockpit vision plot was obtained from crew systems, Bell Helicopter Textron. (See Figure 9) The cumulative plots of all the individual fields of view for the V-22 are calculated to be 230^{o} and are depicted in Figure 10. The C-130 cockpit vision plot was obtained from the Air Force Operational Test and Evaluation Center in Marietta, Georgia. (See Figure 11) The cumulative plot of all the fields of view for the C-130 are 260^{o} and are depicted in Figure 12.

Probability of Detection and Field of View Plots

By correlating the relationship between the probability of detecting a searching patrol aircraft and the cumulative FOV from both the V-22 and C-130, a determination of the POD zones is obtained. These zones provide a means for determining the mutual support distances within a formation. The zones are calculated by averaging the POD ranges and then utilizing the maximum distance for each range to determine a POD. As a result, the 50% POD zone is 2 - 2.65nm while the 75% POD zone is 1.6 - 2nm.

The question remains, how does the individual aircraft FOV restriction effect formation flight or to what degree can a poor FOV be overcome through optimization of mutual support? It is obvious that the FOV weaknesses of individual aircraft will manifest themselves in subsequent formations contributes to the development of blind areas around or behind the formation. These blind areas, particularly in the rear hemisphere of the formation, present a significant challenge to formation development. The challenge for the assault support community is to minimize the blind area to a degree that will allow aircrew enough time to detect an incoming aircraft and then alert the formation. The key to this problem is finding the distance at which the incoming aircraft must be detected before it reaches its weapons employment distances. (See Table 1) For further development of employment distances and correlation to acceptable blind area distances from the formation, refer to the appropriate threat reference guide. A graphic representation of the V-22 and C-130 cumulative FOV/POD plots for determination of the blind area distances are provided for evaluation and comparison of differing formations. (See Figure 13)

Development of Optimized Formations

To optimize an aircraft formation it must adhere to a standard. The formation principles derived in Chapter 2 are the standards for determining optimization. The primary source of strength for any formation is its mutual support. Based on the cumulative FOV if **mutual support** is optimized through distance and position, then maneuverability will be enhanced through freedom of action. It follows logically that **flexibility** is also enhanced due to the type of formation, the lateral separation and number of aircraft. **Protection** for the V-22 and C-130 is inherent in its mutual support and speed. **Command and control (C^2)** and **unity of effort** are principles that the flight lead must organize through the formation elements to achieve. It should be noted that the lateral separation distances required to optimize mutual support, might need to be reduced to facilitate C^2. This is viewed as an exception vice the rule and should only be considered at the detriment of the other formation principles. All aircraft in the formation have **self-navigation** responsibilities, but the lead aircraft (flight lead) normally assumes the responsibility for navigation of the flight. As a result, the principles of mutual support, maneuverability and flexibility are the only principles to be utilized for determining optimization.

Maneuver Elements

The method of analysis for determining our new formations will not be to re-evaluate all of the formations currently in use, to see if they're optimized. We will use, instead, the POD and cumulative FOVs to manipulate aircraft positions on a scaled chart to determine optimum formation(s). (See Figure 13, 14 and 15) The base of our formation(s) is the section (two aircraft). Therefore, we will commence our analysis with the section, followed by a division of three and four aircraft.

Section

For a section, the principle of mutual support will be optimized first. For this to occur, both aircraft need to occupy a position relative to one another that would allow for overlapping fields of view. This provides a complimentary means to detect and warn of an impending airborne attack. By manipulating the aircraft in Figure 13 to achieve this position, it becomes apparent that the optimum **mutual support** for the section is obtained in a spread formation with approximately 9,000-10,000 feet or 1.5-1.7nm between aircraft. (See Figures 16 and 17) By manipulating the aircraft plots further, you can see that maximizing mutual support is detrimental. The vulnerability of the formation is increased due to the encroachment of the blind area aft of the formation. The size and location of the blind area allows an aircraft to approach the formation undetected and achieve an uncontested weapons engagement opportunity. The principle of **maneuverability** is very high due to the lateral separation but requires a higher degree of coordination. This coordination could be facilitated by flying a bearing line just aft of the abeam position, i.e., an 80-85^{o} bearing line. The spread formation presents a very difficult target to attack from the air, due primarily to the position of the aircraft. Lateral separation and a lead/dash-two relationship of the section ensures the principle of **flexibility**. The relative positions of the aircraft allow for rapid maneuver to alter formation position to counter an airborne attack.

Division

For a division (three or four aircraft), the number of aircraft begins to increase the formation's POD. To minimize the POD, maximum lateral separation within the formation is critical. In the three-aircraft division, it is readily apparent that the third aircraft contributes significantly to optimization of **mutual support**. By overlaying the third aircraft into a lead position, (approximately 6,000-8,000 ft), creating an inverted "Y" formation, the basic section remains unchanged and free to maneuver. The lead aircraft concentrates on navigation and lookout focused in the forward hemisphere 10 to 2 o'clock. The lead's rear hemisphere is completely covered by the overlapping mutual support provided by dash-two and dash-three. The primary sector of responsibility for dash-two and dash-three, however, is the formation's vulnerable rear hemisphere. The beauty of the inverted "Y" formation is that the additional aircraft in the lead position has no detrimental effect upon **maneuverability** or **flexibility**, but it does increase mutual support. Therefore, from a mutual support perspective, the inverted "Y" formation is the optimum formation. (See Figures 18 and 19)

The four-aircraft division will create an even greater increase in the POD, if dispersion is not maintained. If it is true that a section spread formation is optimized for mutual support and a third aircraft has no detrimental effect on maneuverability, overlaying a second section in an off-set box formation should also optimize **mutual support.** (See Figure 20 and 21) Similar to the inverted "Y" formation, the distance between sections will facilitate maneuverability. Coordination needs to be standardized to a higher degree. Two flights of two in front of one another create challenges to maneuvering. For example, the formation is attacked and the lead section is split down the middle. The threat reaction breaks the lead section left and right. The second section's threat reaction is limited through timing and direction of turn, but only slightly. The difficulty lies in additional follow-on maneuvers and fear of striking a wingman. The overall **maneuverability** remains high for initial turns, but decreases thereafter. **Flexibility** remains high, as long as the sections function as two separate sections within a division.

Optimized Formations

The end result of the analysis is that the following new formations for the V-22 and C-130 are as follows (See Figures 16 - 21):

• Section	Spread formation V-22 (Lateral separation 10,000 ft with an 85^o bearing line or greater) C-130 (Lateral separation 9,000 ft with an 85^o bearing line)
• Division (3 aircraft)	Inverted "Y" formation V-22 (Lead/-2 separation 6,000-7,000 ft) (-2/-3 same as section) C-130 (Lead/-2 separation 7,000-8,000 ft) (-2/-3 same as section)
• Division (4 aircraft)	Offset Box V-22 (Lead/-3 separation same as division) (Lead/-2 and –3/-4 same as section) C-130 (Lead/-3 separation same as division) (Lead/-2 and –3/-4 same as section)

Advantages and Disadvantages

The advantages of the section spread formation are optimized mutual support by maximizing the POD of inbound aircraft. By optimizing mutual support through lateral separation you achieve maximum maneuverability and minimized your own POD. Flexibility is maintained due to positioning. The three-aircraft division inverted “Y” formation is the best overall formation for achieving mutual support. It balances the entire flight by relieving the base section (dash-two/dash-three) from the primary responsibility of lookout in the forward hemisphere. This allows dash–two/dash-three to concentrate their lookout along the flanks and rear hemisphere of the formation rather than trying to cover the entire FOV.

The disadvantages of any of the V-22/C-130 formations are the weak FOV designs. “The reason the C-130 has a poor FOV is that it was born in concept from the Korean War. It was intended as a replacement for the piston-driven C-54, C-124, C-119, C-47 and C-46 aircraft. Consequently, the C-130 was designed as a medium-sized tactical transport devoid of concerns for infiltrating patrolled airspace.”[1] It has, however, seen its mission expanded to include tactical assault landings for troop insertions, penetration refueling and other missions that put it in harm’s way. Fortunately, the C-130 has kept pace through modification of the aircraft with observation blisters or rear vision devices increasing its FOV and reducing its vulnerability. The V-22, on the other hand, seems to have been developed without a balanced FOV design. This lack of FOV design decreases the individual aircraft’s ability to achieve a maximum lookout while minimizing vulnerability. It is possible to achieve mutual support, but the formation cannot completely overcome design weaknesses to create an ideal formation. Therein lies the biggest disadvantage of the new formations. The formations can only optimize existing conditions and cannot overcome inherent FOV design flaws. If the V-22 had 80^{o} more FOV, the design flaw could be minimized to provide the mutual support that could significantly increase combat survivability.

Notes

[1] Dabney, Joseph E., *HERK: Hero of the Skies*, Copple House Books Inc., Lakemont, GA, Revised Edition 1986, Pg. 83

Chapter 7

Summary: Recommendations

The development of flight formations based on the ability to detect incoming aircraft and optimized for mutual support succeeded in providing some basic observations. Assault support aircraft must use every counter tactic available to defend themselves against the increasingly lethal and offensive nature of airborne attacks. To accomplish this, it is crucial to take advantage of the low altitude regime to diminish the enemies' capability to acquire and target assault support aircraft. To further enhance survivability, an aircraft must have a low-contrast signature to decrease its probability of detection. The ability of formations to optimize mutual support and the other formation principles are critical to survival. Formation size and movement within the formation are significant contributing factors to detection and must be kept to a minimum. The section will remain the maneuver base for flight formations. The division (three aircraft), however, optimizes mutual support but increases its POD. The four aircraft division will also rely on dispersion, but other formation principles such as flexibility and maneuverability will begin to see some degradation. Future research and development must be directed towards determining the degree of movement, which can be allowed, within a formation. Additional movement may help compensate for the reduced FOV and aid in reducing the blind area behind the formation(s). Dispersion also has to be investigated through flight tests to validate the practical limits of formation lateral separation and mutual support. Additionally, any formation that is optimized according to the formation principles will possess significant benefits against ground threats.

Appendix A

Figures

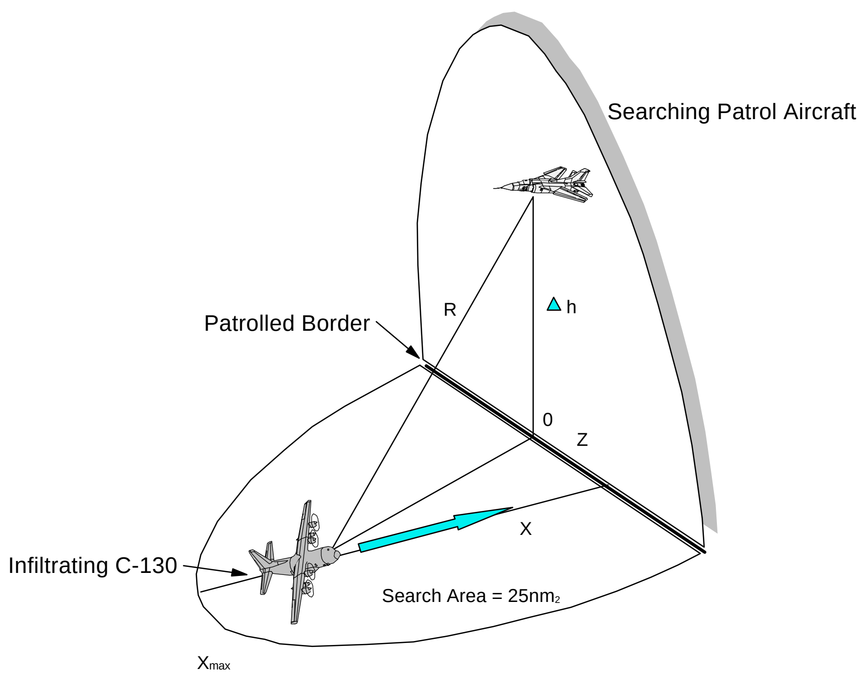


Figure 1. Search Problem Geometry, Look-up Search

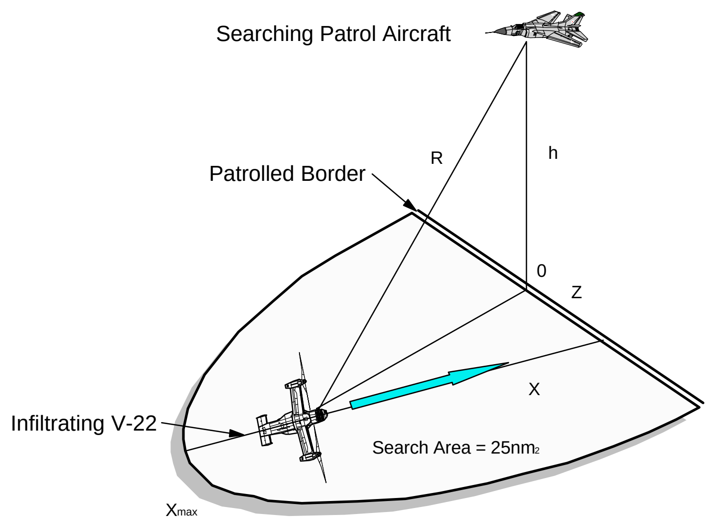


Figure 2. Search Problem Geometry, Look-down Search

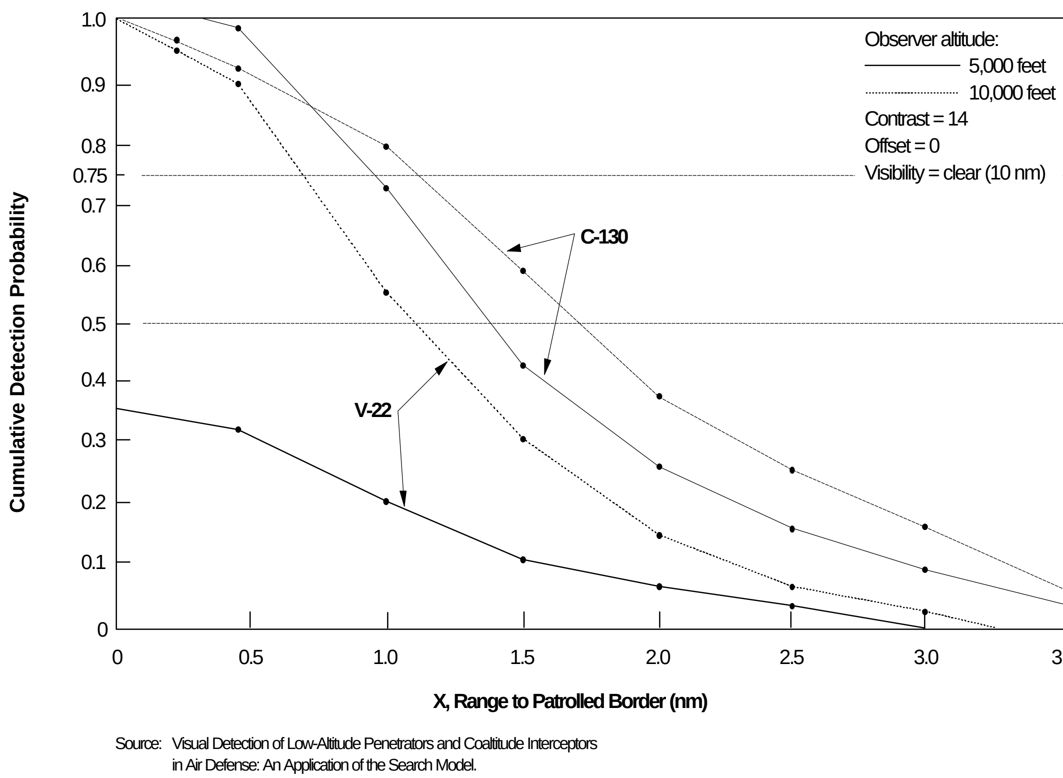
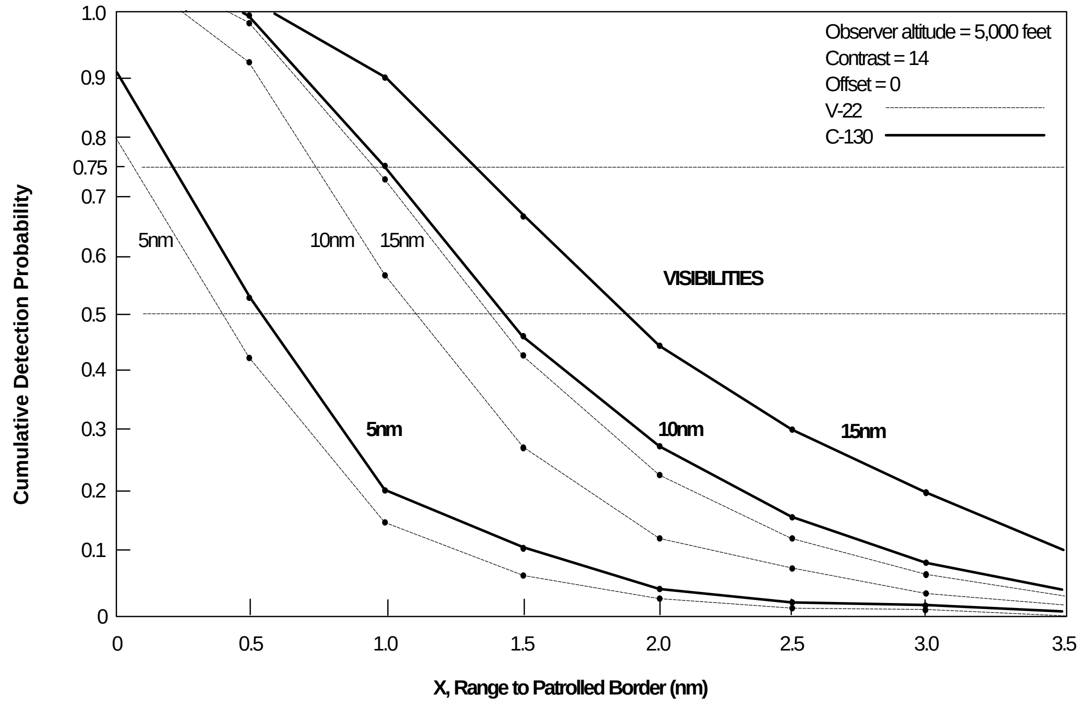
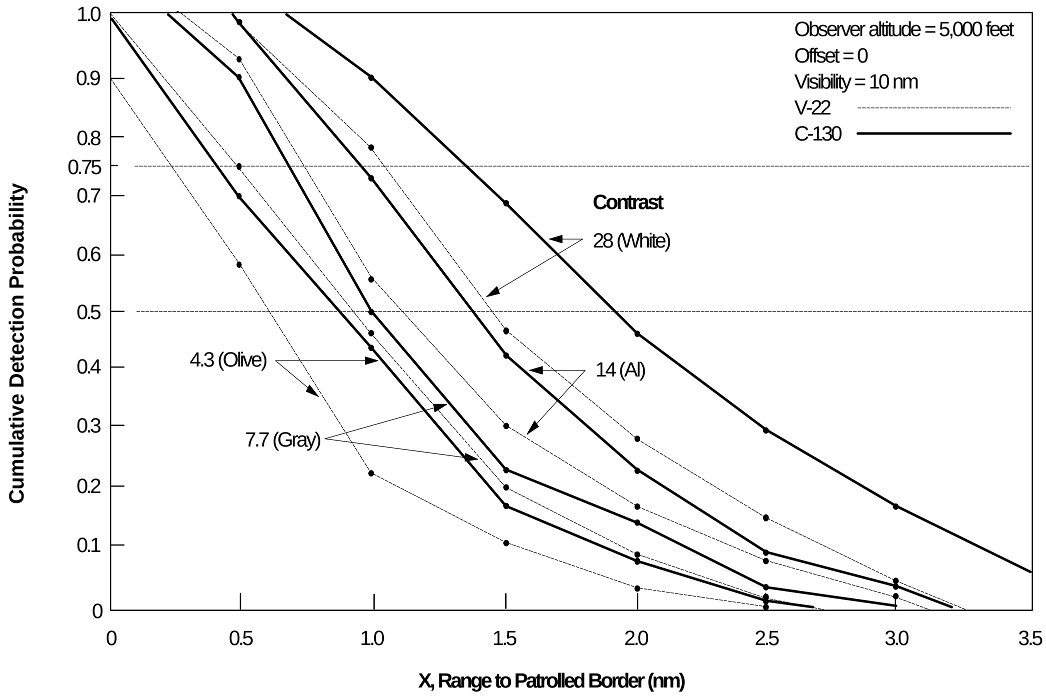


Figure 3. Effect of Infiltrator Size on its Detectability



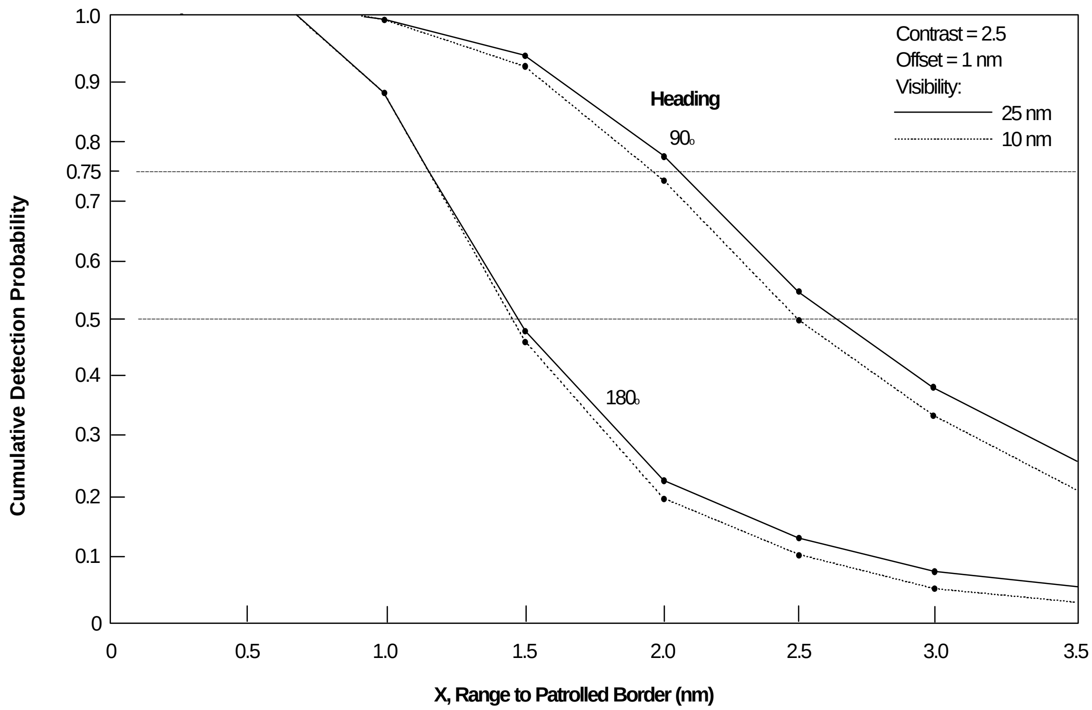
Source: Visual Detection of Low-Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model.

Figure 4. Effect of Visibility on Detectability of Infiltrating V-22 and C-130



Source: Visual Detection of Low-Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model.

Figure 5. Effect of Contrast on Detectability of Infiltrating V-22 and C-130



Source: Visual Detection of Low-Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model.

Note: Data was derived from coaltitude case study. Viewing from low to high may change the target aspect angle and POD distance.

Figure 6. Effect of Visibility and Heading in Look-up Search

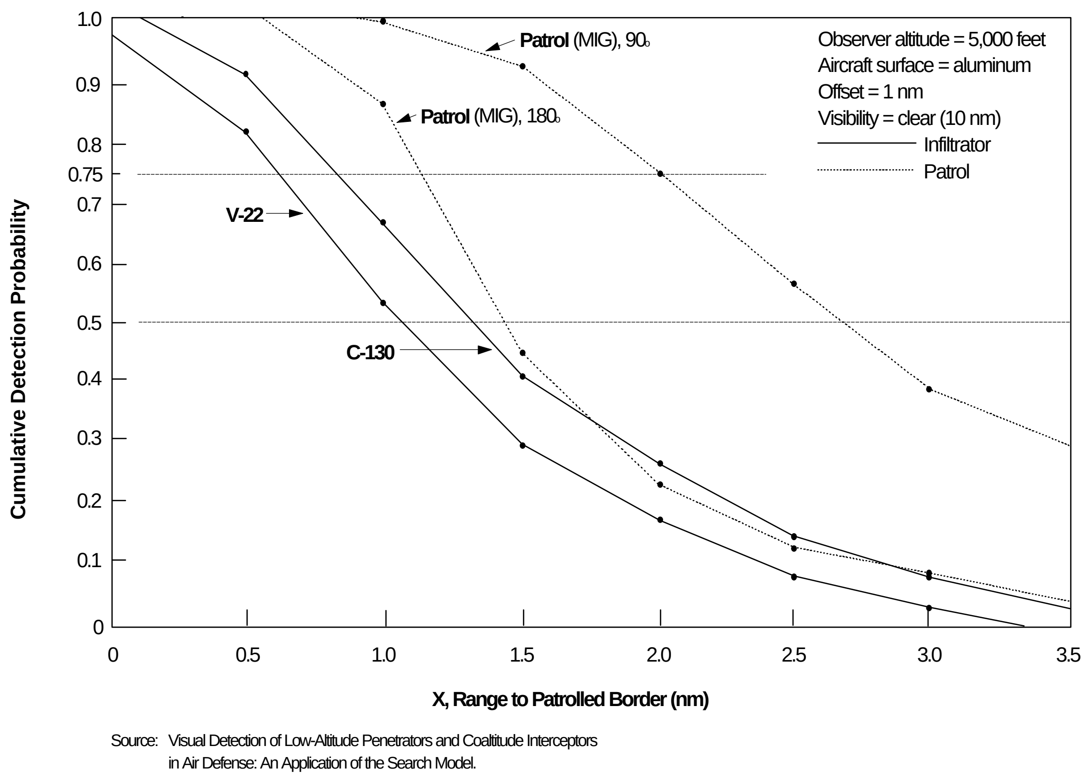
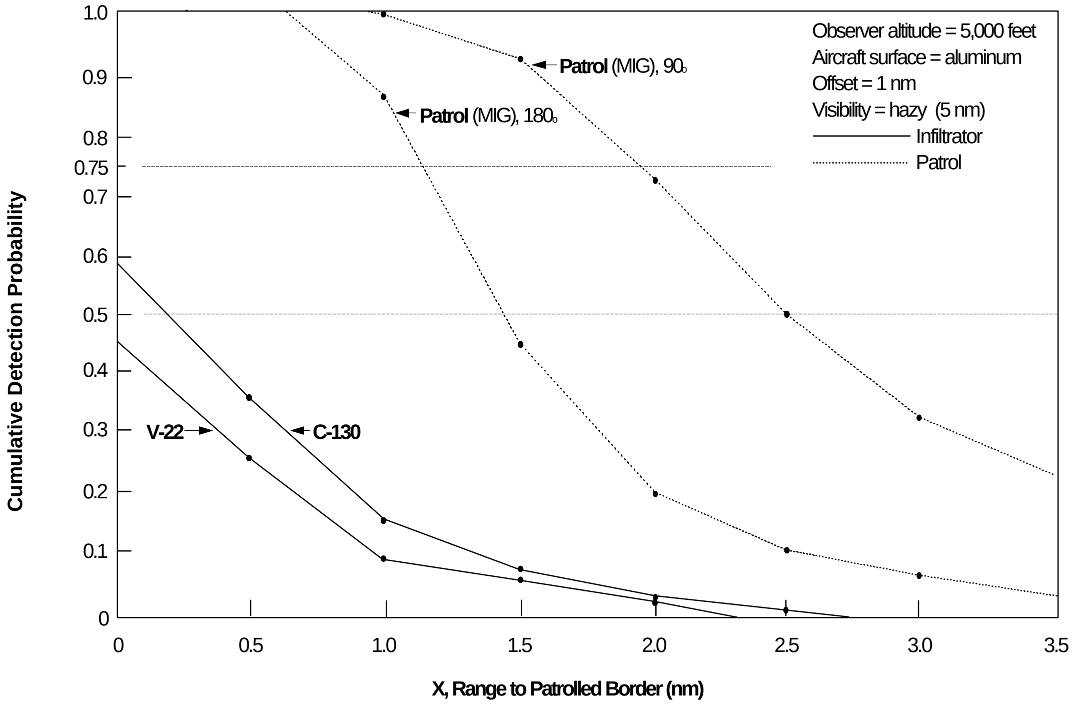
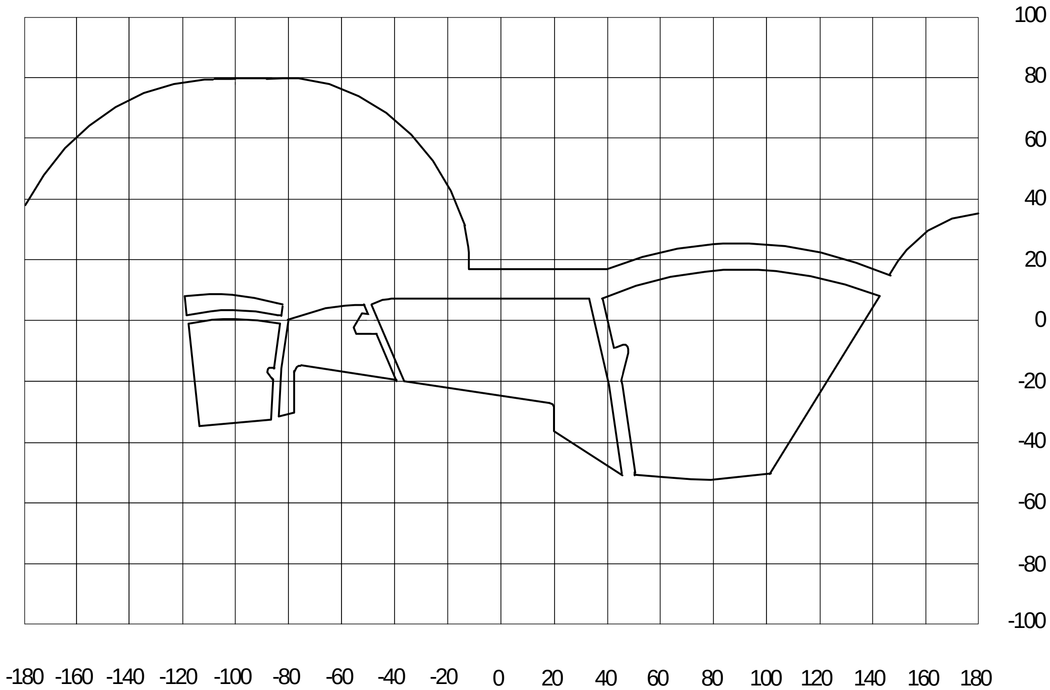


Figure 7. Comparative Detectability of Infiltrators and Patrol Aircraft in Clear Weather (10nm)



Source: Visual Detection of Low-Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model.

Figure 8. Comparative Detectability of Infiltrators and Patrol Aircraft in Hazy Weather (5nm)



Source: Crew Systems, Bell Helicopter Textron Inc., Hurst, TX.

Note: The pilot/copilot (furthest aft eye position) have the capability in the vertical plane to see -24°/+18° (over the nose of the aircraft), and 130° L/R in the horizontal plane. The left seat plot is identical to the right, flip 180° for orientation.

Figure 9. V-22 Cockpit Vision Plot (Right Seat-Furthest Aft Eye Position)

Note:

Located within the troop/cargo compartment area, there are four windows. Two 12-inch circular windows are located along the left side of the aircraft, beneath and just fore and aft of the wing. The other two windows are located on the right side of the aircraft. The first one is a 4.75-inch circular window, located just behind the cockpit. The second window is aft of the wing and is identical in size and location to the aft window on the left side of the aircraft. The FOV for each was calculated accounting for binocular vision with a 12-inch viewing distance, allowing for 1.25 inches of head movement. As a result, the FOV for the 4.75-inch window was 22.4° circular plot. The remaining 12-inch windows had a 53.1° circular plot. The FOV from the windows located within the troop/cargo compartment area are restricted along the beam (90°) when the aircraft is in the airplane mode (engine nacelles horizontal), because the engines block the aircrew line of sight. It is also important to note that both the V-22 and C-130 cockpits obtained a maximum FOV by body displacement. Due to aircrew mission tasking, this was not considered a true reflection of the aircraft/aircrew FOV, and a practical limit of 90° L/R from the cockpit was imposed.

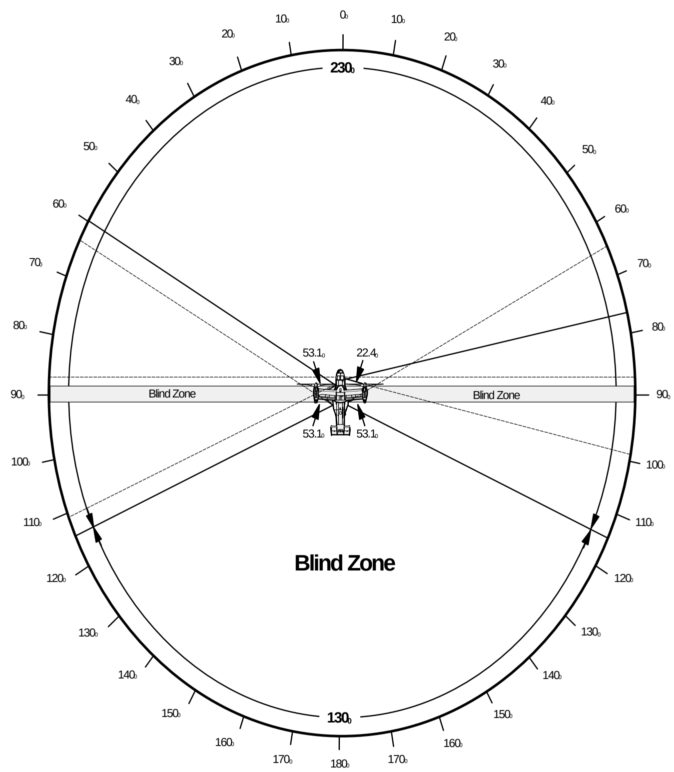
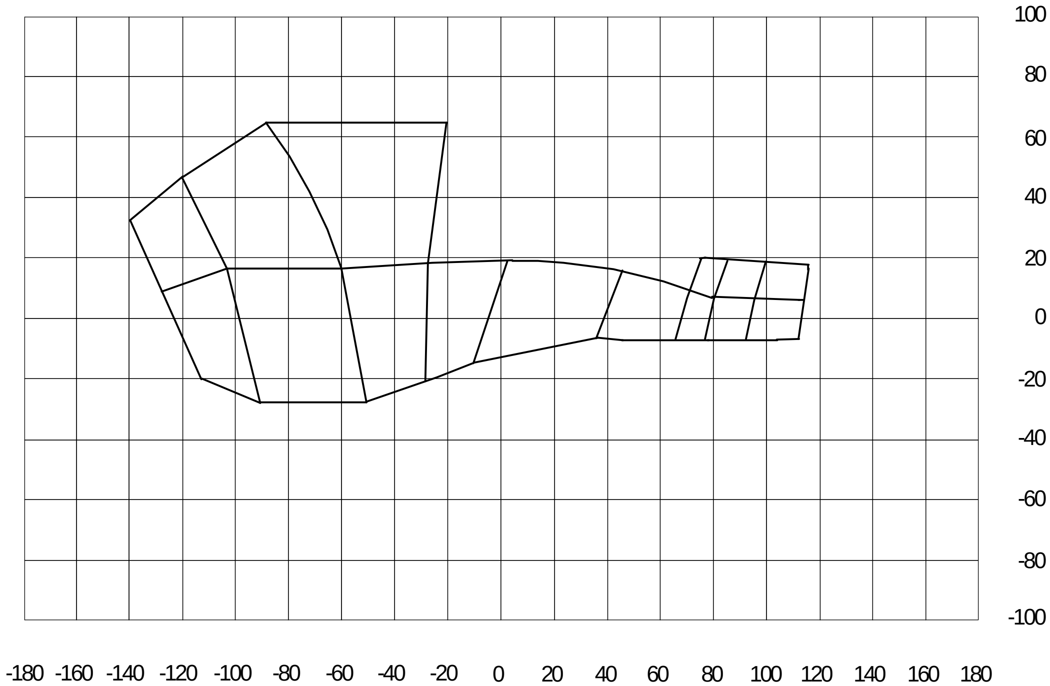


Figure 10. V-22 Cumulative FOV Plot



Source: Air Force Operational Test and Evaluation Center, Marietta, GA

Note: The pilot/copilot (eye position unknown) have the capability in the vertical plane to see +22° and -15° (over the nose of the aircraft), and 120° L/R in the horizontal plane. The right seat plot is identical to the left, flip 180° for orientation.

Figure 11. C-130 Cockpit Vision Plot (Left Seat-Eye Position Unknown)

Note:
Located within the troop/cargo compartment area there are numerous circular windows, but only the two paratroop door windows (16-inch vertical x 15-inch horizontal) were utilized for calculating the cumulative FOV. They are located well aft, just prior to the ramp and door in the tail (empennage). The FOV for each was calculated accounting for binocular vision with a 12-inch viewing distance, allowing for 1.25 inches of head movement. As a result, the FOV for the vertical plot was 64° and 58.7° for the horizontal plot. It is important to note that both the V-22 and C-130 cockpits obtained a maximum FOV by body displacement. Due to aircrew mission tasking, this was not considered a true reflection of the aircraft/aircrew FOV, and a practical limit of 90° L/R from the cockpit was imposed.

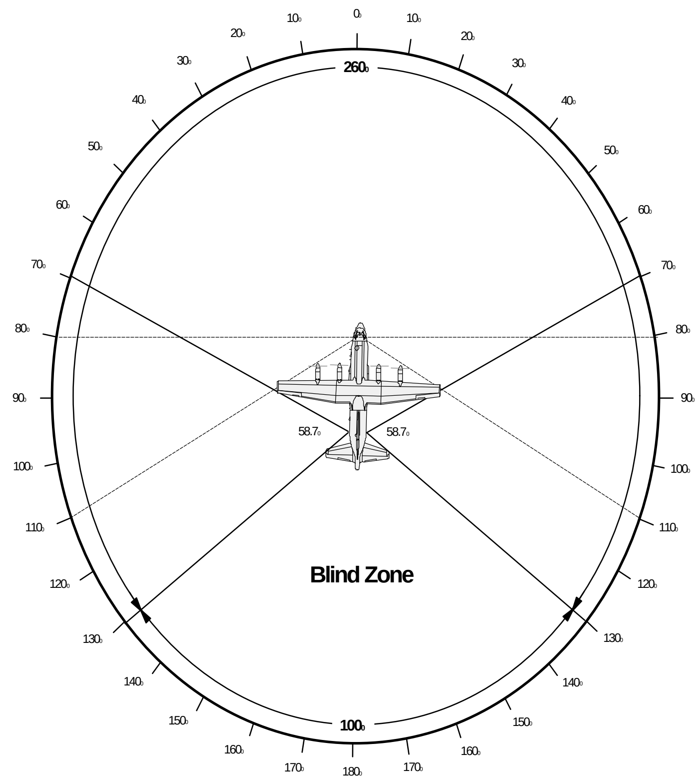


Figure 12. C-130 Cumulative FOV Plot

POD/FOV Evaluation Chart
on File at ACSC

Figure 13. POD/FOV Evaluation Chart

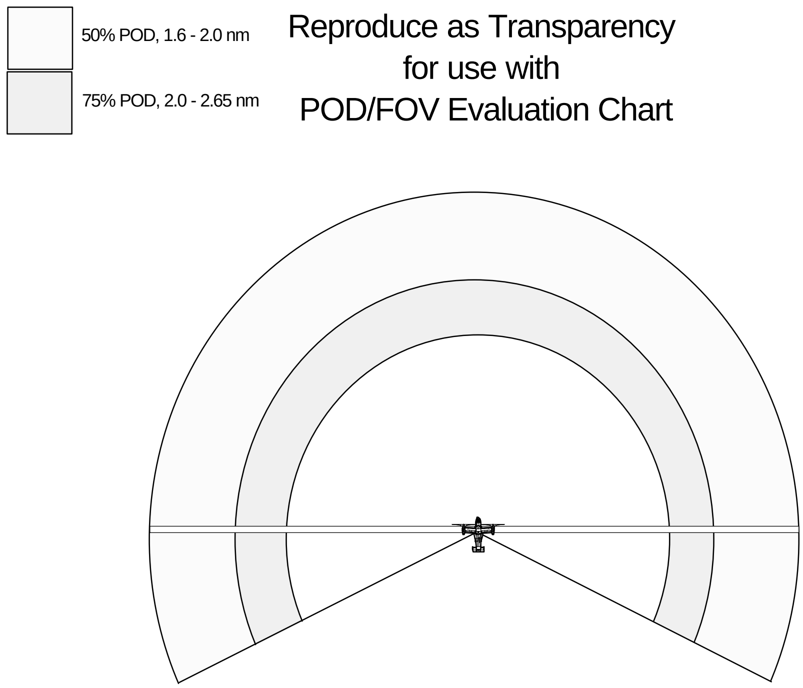


Figure 14. V-22 POD/FOV (230°) Overlay

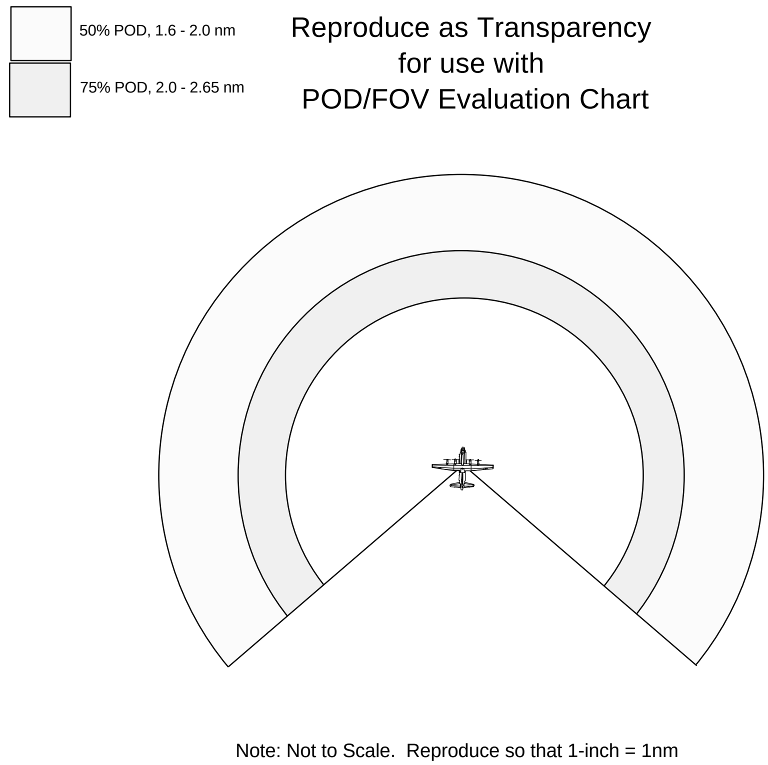


Figure 15. C-130 POD/FOV (260°) Overlay

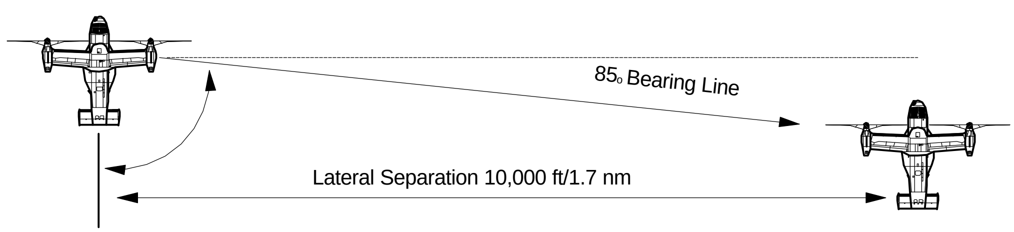


Figure 16. V-22 Spread Formation

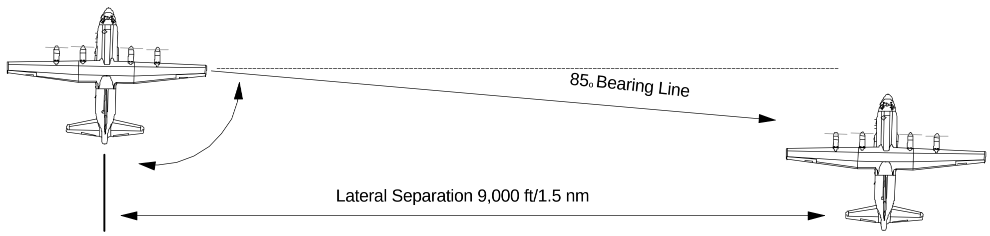


Figure 17. C-130 Spread Formation

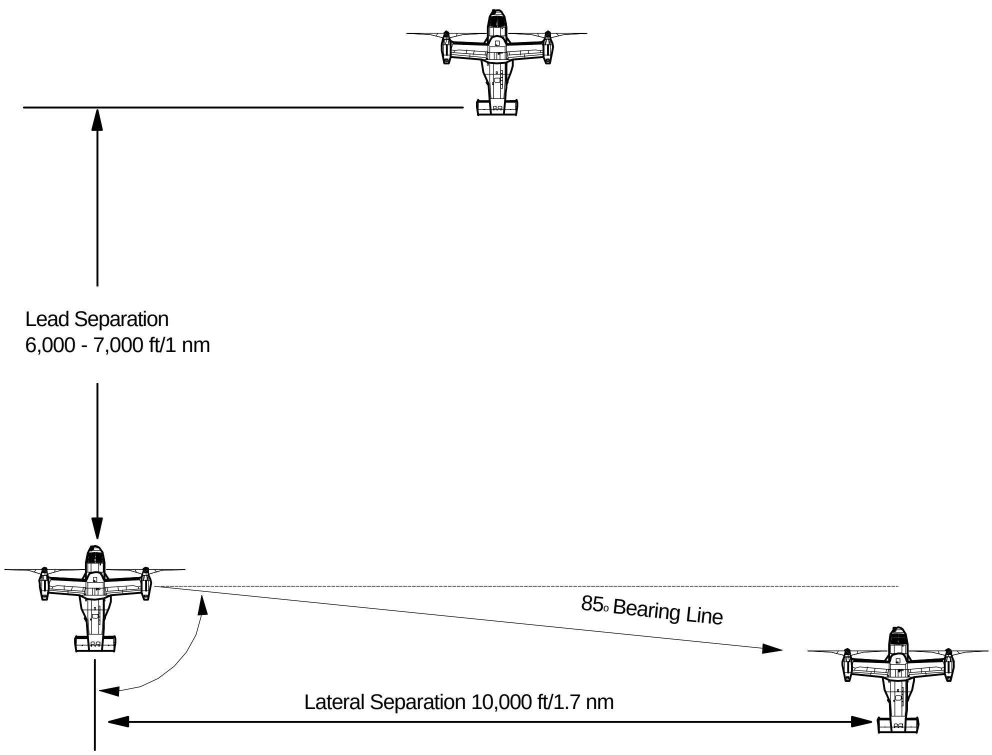


Figure 18. V-22 Inverted "Y" Formation

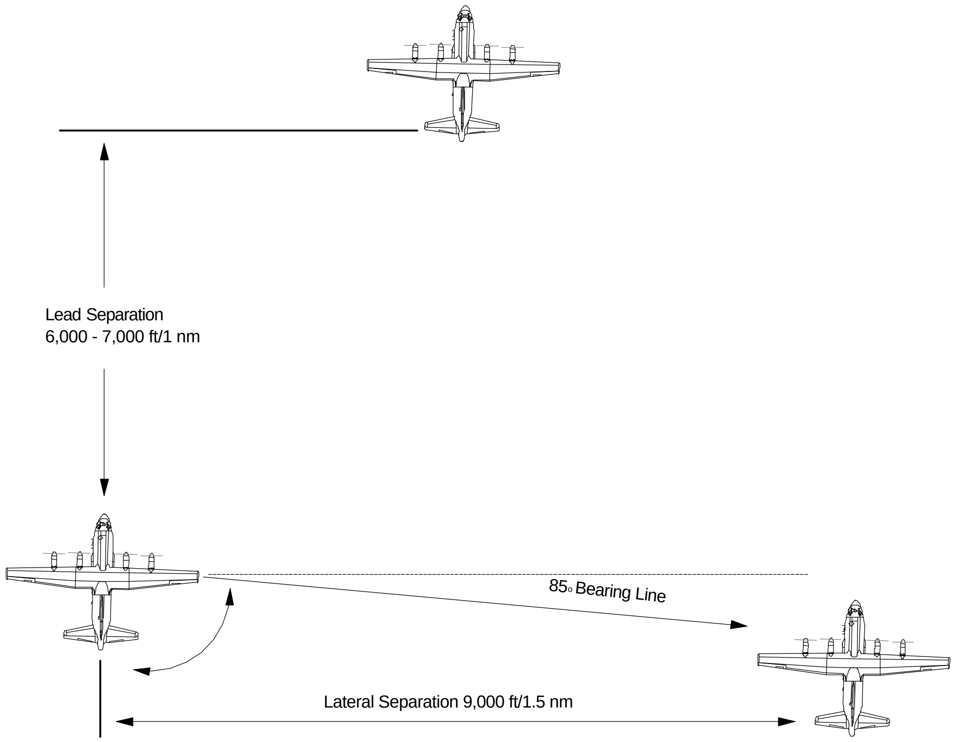


Figure 19. C-130 Inverted "Y" Formation

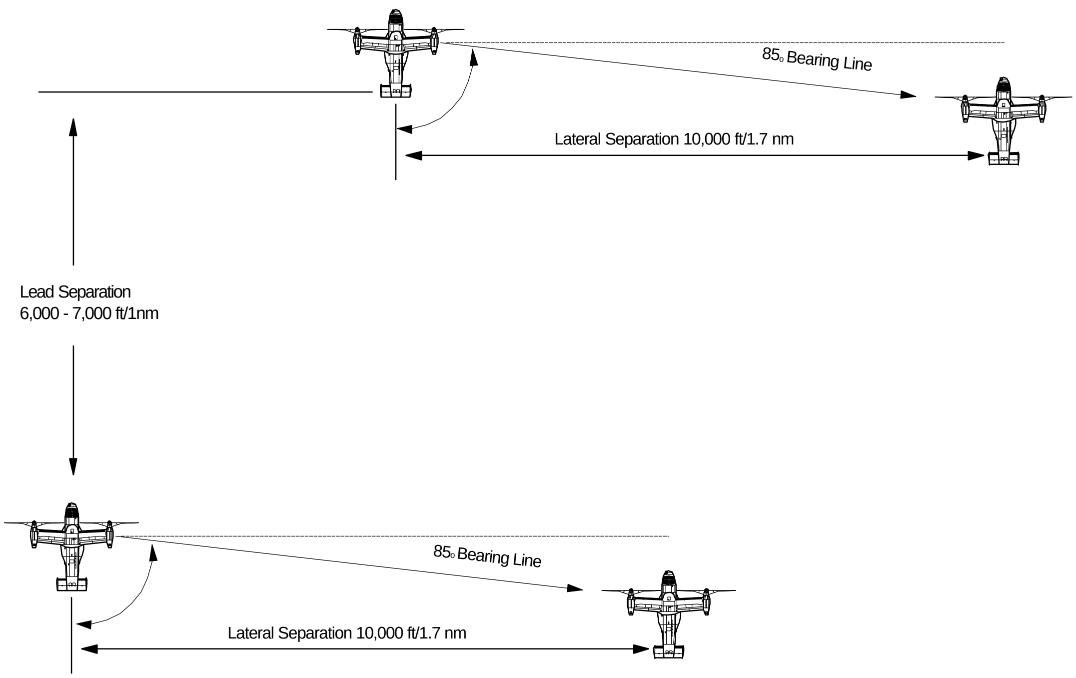


Figure 20. V-22 Offset Box Formation

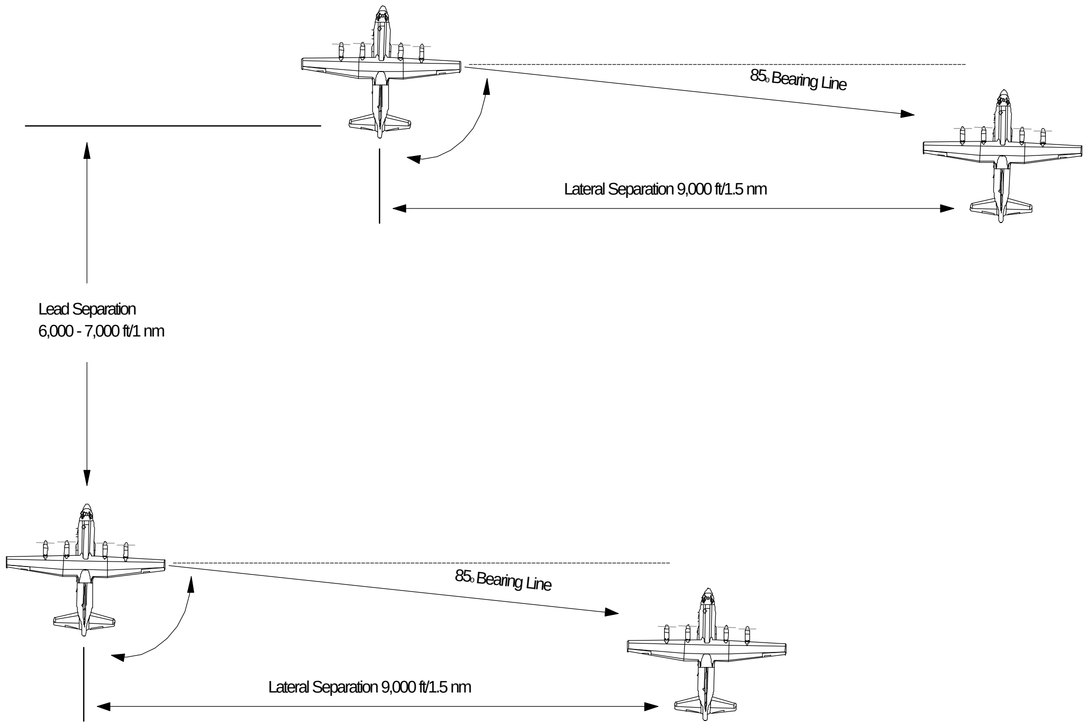


Figure 21. C-130 Offset Box Formation

Appendix B

Tables

Table 1. Visual Distance Estimation

1/4 Mile	1,520 Feet	Approx. AA max. effective range (1,500 to 3,000 Feet)
1/2 Mile	3,040 Feet	
1 Mile	6,080 Feet	Approx. IR AAM minimum range (1 mile)
2 Miles	12,160 Feet	*Approx. Radar AAM range utilized for formation planning
3 Miles	18,240 Feet	

*Consult appropriate threat reference guide for planning considerations for Radar AAM.

Source: KC-130 Tactical Manual, NWP 3-22.5-KC-130, Vol. I, May 1997, Chapter 13, KC-130 Defensive Tactics.

Table 2. Visual Detection of Moving Targets: Field Test Data

Target	Target Speed (Knots)	Target Altitude (Feet)	Observer Altitude (Feet)	Search Area or Sector	Background	Visibility (nm)	Range at 50% Detection (nm)	Remarks
B-47, painted OD	300-400	<500	5,000 and 20,000	10 x 45 nm	Swamps, woods, and fields in Northwest Florida	VFR	2 - 7	Pilots' estimate of average detection range.
F-101, Camouflaged; F-4, Uncamouflaged in groups of 1, 2, or 4	400-530	50-500	6,000	15 x 15 nm	Florida (swamps, woods) or California (desert, mountains)	8 - 15	2.5	Camouflaged aircraft less obvious over woods, more obvious over desert. Multiple aircraft detected more often than single.
MIG-17 or MIG-21	Subsonic	5,000 - 15,000	5,000 - 15,000	360°	Sky (Variable)	Varied	2.4	Combat encounters in Southeast Asia.
Navy aircraft (Sea Vampire or Sea Fury)	360	100, 1,000, 3,000, 5,000	Seaside cliff	10° or 60°	Sky (Clear blue or cloudy)	8 - 12	2.6a 3.3b	ground observers were alerted when the aircraft was approaching.
F-4, F-105, A-6A	360-550	0 - 900	0	Approx. 90°	Sky (Usually cloudy) or sometimes hilly terrain	...	2.6	Smoke trails important clue in detecting F-4, aircraft noise aided detection in 17% of cases.

a For 60° search sector.
b For 10° search sector.

Source: Visual Detection of Low-Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model.

Glossary

C^2	Command and Control
C-46	The C-46, “Commando”, is a military transport powered by two Pratt & Whitney radial cooled engines and was built by Curtiss Aviation.
C-47	The C-47, “Skytrain”, is a military transport powered by two Pratt & Whitney radial cooled engines and was built by Douglas Aviation.
C-54	The C-54, “Skymaster”, is a military transport powered by four Pratt & Whitney radial cooled, super charged engines and was built by Douglas Aviation.
C-119	The C-119, nick named “The flying box car”, is a military cargo-transport powered by two Pratt & Whitney radial cooled engines and was built by Fairchild Hiller Aviation.
C-123	The C-123, is a tactical transport powered by two radial cooled engines and augmented with two General Electric pylon mounted jet engines. It was built by Fairchild Hiller Aviation.
C-124	The C-124, “Globemaster”, is a military cargo-transport powered by four Pratt & Whitney radial cooled engines and was built by Douglas Aviation.
C-130	The C-130, “Hercules”, is a tactical transport and multi-mission aircraft powered by four Allison turbo prop engines and is built by Lockheed-Georgia (Martin) Aviation.
CH-46	The CH-46, “Sea Knight”, is a tandem rotor medium lift transport helicopter powered by two engines and built by Boeing Aviation.
CH-47	The CH-47, “Chinook”, is a tandem rotor medium lift transport helicopter powered by two engines and built by Boeing Aviation. It is very similar to the CH-46.
CH/MH-53	The CH-53, “Sea Stallion”, is a heavy lift transport helicopter powered by two engines and built by Boeing Aviation.
FOV	Field of View
METT-TS-L	Mission; Enemy; Terrain and weather; Troops and fire support; -Time; Space; - Logistics
POD	Probability of Detection

UH-1	The UH-1, “Iroquois”, is a utility helicopter powered by two engines and built by Bell Aviation.
USAF	United States Air Force
USMC	United States Marine Corps
V-22	The V-22, “Osprey”, is a twin engine tilt rotor multi-mission aircraft and built by Bell-Boeing Aviation.

Angular Motion. The angular motion (velocity) of a target with respect to an observer. For this research project, the speed of the target, its offset, range and heading has an impact on angular motion and subsequent POD.

Aspect Angle (Relative heading). The viewing angle from a target to the observer. If, for example, the observer and target were headed directly towards one another with no offset, then the aspect angle would be 180^{o}. If the target and observer were perpendicular to one another then a 90^{o} aspect angle exists.

Binocular Vision. In large mammals and humans, both eyes share a large portion of the visual field. Binocular vision is the neural and psychological interaction of the two eyes within the region of overlap.

Contrast. The measure of illuminance difference between a target and its background.

Central Vision (Fovea). A localized region of the retina, close to the optic axis of the eye, populated exclusively by cones. It is essentially the region of the retina that is employed for accurate vision.

Depth Perception. The judging of distance and the perception of motion in the visual field.

Division. A division is made up of two or more sections and serves as a mechanism for controlling a large number of aircraft. Within the division the sections will function to facilitate organization and control.

Field of View. The total view area usually expressed in degrees.

Illumination. Also called illuminance, the amount of light measured in lumens per unit area, that intercepts a surface at any given point. The amount of light striking a surface.

Lookout Doctrine. A method of conducting a systematic external visual scan to ensure coverage of the aircraft’s entire FOV and subsequent detection of aircraft, missiles and or obstacles. Additionally, lookout doctrine encompasses the knowledge and application of aircrew training, distance and range estimation to a visual scan.

Luminance. It is the amount of light per unit area reflected from or emitted by a surface.

Nacelle. The enclosed protective shell that fits around an aircraft engine.

Observation Blisters (Rear Vision Device). A device usually fitted or fashioned into an existing hatch or the modification of an existing window to improve the FOV for the conduct of visual searches or observations.

Peripheral Vision. Relates to the ability of the eye to see objects outside the area providing the eye’s central vision. Central vision utilizes cones in the central portion of the eye to provide superior detail, color, and a motion perception but requires relatively high illumination. Peripheral vision utilizes rods, located around the periphery of the eyes central vision, to perceive targets during low light conditions and detect motion.

Section. The basic element of a formation and is normally made up of two aircraft. (See division)

Snellen Acuity. It is the measurement of visual acuity by the ophthalmologist or optometrist utilizing the Snellen chart, which uses rows of letters whose details subtend progressively smaller angles at the eye.

Vigilance. A state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment.

Vigilance Decrement. A deterioration in the ability of the observer to remain vigilant for critical signals with time, as indicated by a decline in the rate of correct detection of signals over a continuous period of performance.

Visual Acuity. The measurement of the resolution capabilities of a visual system in terms of the smallest high-contrast detail to be perceived at a given distance.

Bibliography

Books

American Institutes of Research, *Human Engineering Guide to Equipment Design* (Revised Edition), Washington, D.C., 1972.

Boff, Kaufman and Thomas, James P., eds. *HANDBOOK OF PERCEPTION AND HUMAN PERFORMANCE: Vol. I, Sensory Processes and Perception, Vol. II, Cognitive Processes and Performance*, John Wiley and Sons, 1986.

Dabney, Joseph E., *HERK: Hero of the Skies*, Lakemont, GA, Copple House Books Inc., Revised Edition 1986.

Sanders, M.S. and McCormick, E.J., *Human Factors in Engineering and Design*, McGraw Hill, NY, 7th Edition 1993.

Wiener, Nagel David C., *Human Factors in Aviation*, Academic Press Inc., 1988.

Woodson, Wesley E., *Human Engineering Guide for Equipment Designers*, U.S. Navy Electronics Laboratory, San Diego, 1954.

Wyburn, Pickford, and Hirst, R.J., *Human Senses and Perception*, University of Toronto Press, 1964.

Periodicals

Blesse, Maj. F., C., “No Guts, No Glory”, *Fighter Weapons Newsletter Special Issue: Fighter Tactics*, no. 1 (March 1955).

Published Papers

W., L., Van Gilder, *Realistic Training: The Key to success in Aerial Combat*, Fort Leavenworth, KS, 1979.

Reports

Defense Technical Information Center (DTIC), *Low-Altitude Aircraft Detection Probability*, Tactical Air Command, USAF Tactical Air Warfare Center, Eglin Air Force Base, Report no. TAC-TR-65-65, September 1965.

Dugas, Doris, J., *Visual Detection of Low Altitude Penetrators and Coaltitude Interceptors in Air Defense: An Application of the Search Model*, Report prepared for USAF Project RAND, R-885-PR December 1971, Santa Monica CA, 1971.

Tactical Manuals and Other Publications

AFSOC MANUAL 11-1, *Vol. 6, MC-130P, Combat Shadow*, Tactical Employment Manual, Chapter 3, Formation Procedures (Draft), HQAFSOC, 18th FLTS.

AFSOC MANUAL 11-1, *Vol. 9, MH-53J, Pavelow III*, Tactical Employment Manual, Chapter 13, Formation Procedures (Draft), HQAFSOC, 18th FLTS.

AFOTEC OL-JR, Air Force Operational Test and Evaluation Center, Detachment 5, Operating Location JR, *C-130 FOV Plot*, Marietta GA.

Bigelow, GySgt, MV-22 Test, Memorandum, To Jones, Capt., Subject Letter Report, Multi-Operational Test Team Evaluation of the V22 Crew Door and Cabin Windows Field of View, 28 Jan, 1997.

Graf, Virgil, *External Vision Section of the Crew System Design Definition Document (CSDDD) Rev. D.*, Pg. 387 – 392, Bell Helicopter Textron (MV-22).

MCR 55-130 (Multi Command Regulations), Vol. II, C-130 Formation Procedures, 1 August 1993.

USA, *TACTICAL FLIGHT PROCEDURES*, Chapter 7, Multi Helicopter Operations, TC1-201, Headquarters, Dept. of the Army, Washington, D.C., 20 January 1984.

USMC, *NATOPS FLIGHT MANUAL, KC-130 F/R/T Aircraft*, Chapter 14, Special Missions, Formation Flight NAVAIR 01-75GAH-1, February 1996.

USMC, *NATOPS FLIGHT MANUAL (Draft Copy), V-22*, Chapter 9, Special Procedures, Formation and Tactics, A1-V22AB-NFM-000.

USMC, *CH-53 TACTICAL MANUAL*, NWP 3-22.5-CH53, Vol. I, Chapter 2 Formation Flying, NAVAIR A1-H53BE-TAC-000, August 1997.

USMC, *CH-46E TACTICAL MANUAL*, NWP 3-22.5-CH46E, Vol. I, Chapter 3, Tactical Formation Flight, NAVAIR A1-H46AE-TAC-000, July 1997.

USMC *KC-130 TACTICAL MANUAL*, NWP 3-22.5-KC130, Vol. I, Chapter 5, Low Level Formation, Chapter 12, Low Altitude Tactics and Chapter 13, Defensive Tactics, NAVAIR 01-75GAA-1T, May 1997.

USMC, *UH-1N TACTICAL MANUAL*, NWP 55-9-UH1, Vol. I, Chapter 2, Tactical Flight Techniques, NAVAIR 01-110HCE-1T, April 1997.

USAF Historical Research Agency Documents

Air Intelligence Summary No.16-Squadrons, December 31, 1941, R.A.F. Fighting Tactics, The Air Corps Tactical School, Maxwell Field, Alabama, 23 January 1942, Air Force Historical Agency, Maxwell, AFB.

Army Air Forces Intelligence School, Harrisburg, Pennsylvania, Fighter Tactics, Air Force Historical Research Agency, Maxwell AFB.

Stanely, Julian C., Actng. Chief of staff, HQ VIII Air Force, Memorandum, To HQ VIII Fighter Command, Subject Operations, Fighter Tactical doctrines, 20 March 1943.

History, History of Formation Flying in the 1st Bomb Division, Eighth Air Force, England, 1942-1945.

Special Informational Intelligence Report, Office of the Assistant Chief of Air Staff, Intelligence Washington, D.C., *Observations of a Fighter Pilot (P-38)*, May 26, 1943.

Bibliography and Reference

Chennault, C.L., Memorandum for the Commandant, A.C.T.S, Subject *Review of Pursuit Drill Manual*, Maxwell field, Alabama, 20 February 1933.

Holloway, B.K., Col., *High Sub-Sonic Speed for Air Warfare*, Air Power, Air University

Quarterly Review, Fall 1947.
Howard, Templton, W.B., *Human Spatial Orientation*, John Wiley and Sons, 1966.
Institute for Air Weapons Research, *F-86 vs. MiG-15: A Digest of the Briefing on the Analysis of the Korean Air War*, University of Chicago, Museum of Science and Industry, Chicago 37, IL, Contract No. AF 33 (038)-15068, May 19, 1954.
Royce, LtCol., Memorandum from Head Quarters, 1st Pursuit Group, To GHQ Air Force, Selfrigdie Field, Michigan, Subject *Addendum to Group Training Directive,* 8 October 1936.
USMC, *AH-1 TACTICAL MANUAL*, NWP 3-22.5-AH1, Vol. I (Rev. A), Chapter 12, Escort, NAVAIR 01-110HC-1T, April 1997.